A Simplified Approach towards Realizing a 3-D Fax Based On Claytronics

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Abstract

In this paper we describe a model approach to realize a three dimensional copy of an object with the help of claytronics. Claytronics is a form of programmable matter that takes the concept of modular robots to a new extreme. Programmable matter refers to a technology that will allow one to control and manipulate three-dimensional physical artifacts (similar to how we already control and manipulate two-dimensional images with computer graphics). In other words, programmable matter will allow us to take a big step beyond virtual reality, to synthetic reality, an environment in which all the objects in a user's environment (including the ones inserted by the computer) are physically realized.

Here we discuss a way to realize a 3D facsimile starting with image/shape acquisition continuing with transmission and finally the process completing with the 3D realization of the target object. We describe the process of image/shape acquisition with two separate methods where the selection of the method is purely dependent on the object. Transmission can be achieved by conventional means. For the object realization we describe an algorithm which can fulfill the purpose.

I. INTRODUCTION

Most of the literature here that is in this section has been sourced directly from earlier papers on claytronics [1], [2]. The idea is to first acquaint the reader with the concept on claytronics.

The whole purpose of claytronics and our work in particular is to create an ensemble of tens or even hundreds of small autonomous robots which could, through coordination, achieve a global effect not possible by any single unit. One of the primary goals of claytronics is to form the basis or a new media type pario. Pario, a logical extension of audio and video, is a media type used to reproduce moving 3D objects in the real world. A direct result is that claytronics must scale to millions of micron-scale units. Having scaling (both in number and size) as a primary design goal impacts the work significantly. This allows us to render physical artifacts with such high fidelity that our senses will easily accept the reproduction for the original. When this goal is achieved we will be able to create an environment, which we call synthetic reality, in which a user can interact with computer generated artifacts as if they were the real thing. Synthetic reality has significant advantages over virtual reality or augmented reality. For example, there is no need for the user to use any form of sensory augmentation, e.g., head mounted displays or haptic feedback devices will be able to see, touch, pick-up, or even use the rendered artifacts.

A futuristic scenario involving claytronics could go like this. An explorer or a naturalist may come across something interesting in his expedition. If the person wishes to communicate this find with fellow scientists he or she can do it by a normal two dimensional image. However if he wants to go beyond that (i.e. communicate not just with X and Y co-ordinates of that object) but involve the 'depth' and 'feel' of the object then Claytronics would be the solution. Using sophisticated image acquisition techniques, the object can be documented. This can be subjected to various processes and then transmitted. At the receiving end using an ensemble of robotic modules a facsimile of the object can be achieved thus the whole process happening in real time.

II. THE PROCESS IN A NUTSHELL

In this section we briefly go over the entire process we plan to achieve. The complete plan and the details do not form a part of the following literature. They are discussed in greater detail in the design section.

To achieve a complete 3D fax machine there are three parts to the system [3]. Shape acquisition, remote transmission, shape reconstruction. This forms the complete loop. Image acquisition can be of two types. For objects whose 3D fax to be obtained has a very small size (the term small here is greatly dependent on the number of claytronic atoms we are in possession of) we have a way of acquiring the image [3] and for objects very much greater than the mass of the ensemble we propose an entirely different way of acquiring the image. While many papers have discussed the former the latter has rarely been given its due. Our belief is that for claytronics to be fully made use of both are very important because many objects we encounter has its size always greater than the mass of the ensemble. While small objects can be sampled by applying the catoms tightly over the surface the big objects can be handled by sophisticated image processing software. In this paper, we briefly describe a method to acquire a 2 dimensional image. Using several 2D images a rough 3D feel can be given to describe. Here again the correctness of the 3D image that is constructed depends on the object and the number of 2D images from which it is constructed. This 3d 'feel' is stripped to its most basic form, points of interest are marked. Further processing is done and this can be transmitted using sophisticated techniques.

After acquisition and transmission comes the shape reconstruction. For reconstruction we start off with a simple co-ordinate feeding message. For convenience purposes we are developing the algorithm for 2-dimensional shapes only. The algorithm can b extended to 3-dimensional objects too, without much difficulty. For implementing the algorithm to the 2-dimensional shapes a very important generalization has to be made. This generalization is like a 'torch bearer'. It holds good for any kind of 2-dimensional shape. The generalization is that all 2-d objects can be described in the form of co-ordinates. This generalization is fairly obvious. In claytronics however the co-ordinates defining is not restricted to the outline or skeleton of the object alone. The co-ordinates here should describe each and every point in the object. A parallel analogy can be made with Digital image processing. These positions/co-ordinates are obtained at the end of the shape acquisition process. And the object can be better described/realized depending on module size. Lesser the module size greater the number of co-ordinates to better assess the object and realize it and greater the module size lesser the number of basic constituents. Therefore the error here is dependent on the size of the module. Alternatively we can even say that error is dependent on the number of co-ordinates. First let us let us go about the task of achieving 3 dimensional rendering of typical ordinary shapes. Once this is achieved moving on to complex shapes is not difficult. As an illustration we take a real life example and illustrate how to achieve it in 2-dimensional XY frame. The same can be extended to the three dimensional frame. At the receiving end the shape formation algorithm is applied and the fax is obtained. For parallel comparison and correction, the 3d image can be reconstructed. This reconstruction however is done by the computer. A big advantage gained here is the degree to which the fax deviates from the original object is always known and repeated iterations can be done to achieve a greater precision.

Additionally, we draw a parallel between image processing and claytronics, and show that both are 'cut from the same cloth'. We will also show you that, certain cases demand a particular kind of approach and in certain other cases we borrow techniques from actual module motion [4].

III. DESIGN

In this section we give a complete detail of the entire process. The advantages and disadvantages are thoroughly debated and possible extensions to the whole idea are added later on. Let us go about each of these processes starting with shape acquisition. As said earlier basically there are two ways in which shape can be acquired. The applications of claytronics using the camera approach are very vast and profound. Particularly multicamera stereo systems can capture dense shape information which can be transmitted in real time using suitable algorithms [6]. Structured light approaches based on scanning lasers can also be used [7], [8]. Alternatively for faxing small objects we can go for contact sensing where the programmable matter reads the shape of an object by direct contact with its surface.

However, here we also focus on the method of capturing of the image by camera for shape acquisition. For the sake of simplicity and understanding we will show it only in two dimensions

1) *Shape acquisition*

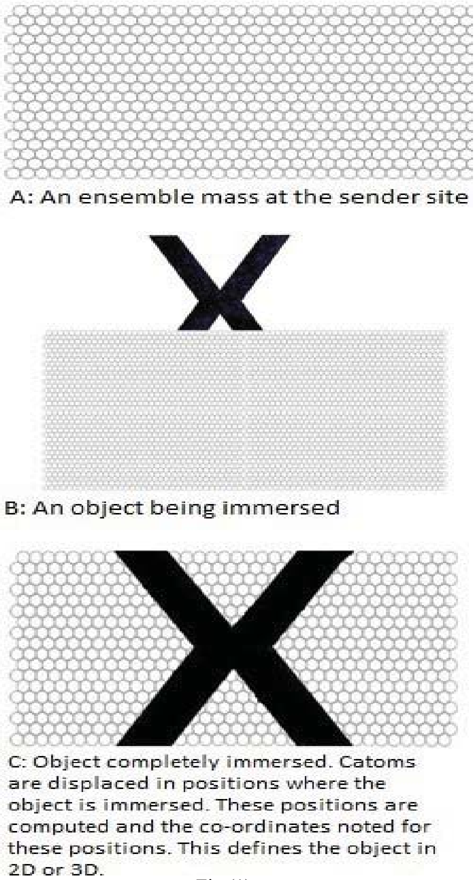
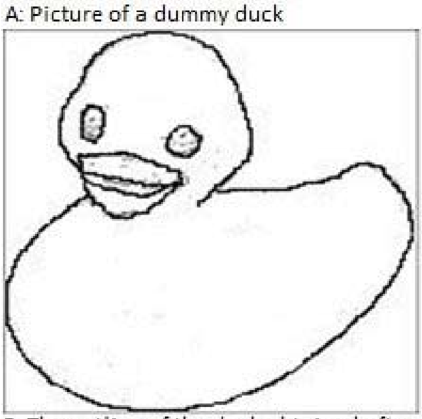


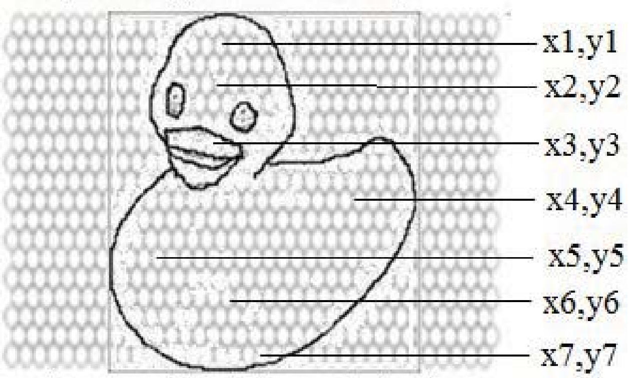
Fig (1)

The process of image acquisition can be done by two techniques. The first is the contact sensing wherein the object is immersed in the ensemble and the catoms can read the shape of the object by direct contact with its surface. This process can be used only for those objects which are small enough to be immersed in the ensemble. Common sense obviously dictates this process cannot be used for buildings, cars, etc. The process starts by immersing the object in the ensemble. When the object is completely immersed and the catoms tightly applied to the object, the ensemble is scanned to recognize which catoms are missing from their regular positions. For effective implementation, the positions of the catoms in default position or when no object is immersed has to be known. This is compared with the catoms whose positions have been displaced i.e. after object immersion. This gives us the co-ordinates that describe the object in space. For proper reconstruction at the receiver side, the coordinates of those positions where the catoms are absent make more sense. Hence the computer now computes the coordinates of the positions where the catoms were displaced. These critical co-ordinates are then transmitted. This process is illustrated in fig.1

A: Picture of a dummy duck



B: The outline of the duck obtained after processing. This method can be used to take 2D images of 3D objects, combine them and after further processing we can get a rough 3D sketch or grid. A simple 2D image is shown for clarity.



C: The outline of the duck is overlaid on the ensemble. For a 3D realization the surface contour is overlaid on a 3D dimensional ensemble. The computer determines the co-ordinates which form a part of the ensemble. These co-ordinates are then stored or transmitted.

Fig (2)

The second and perhaps a more robust technique which can be used for all types of objects is the non-contact sensing. If the object under consideration is a 2-D object, then a single photograph of the object would suffice. As mentioned it is assumed that the computer knows the coordinates of all the catoms. First the photograph of the object is input to the computer. Describing the process in crude terms, the computer takes the outline of the image and overlays this outline on the virtual ensemble. By simple image comparison the catoms that come inside the overlay or form a part of the overlay can be seen. The co-ordinates of these catoms are then taken and stored. When shape reconstruction is required at the receiving end these co-ordinates are transmitted. The process is illustrated in fig.2.

2) Shape reconstruction

Shape reconstruction is the most important step in claytronics. This can be primarily divided into two stages: the activation stage and the grouping stage. We propose methods to achieve each of these.

Activation

At the end of acquisition the computed set of lattice positions is transmitted and at the receiver site we have these positions. These positions can be the Cartesian Co-ordinates for the required shape to be formed. Depending on the object that we wish realize the number of transmitted co-ordinates may vary. These co-ordinates are stored at the site, till we wish to achieve the realization. Initially the ensemble is powered on, but the catoms are still in the dormant state. The first step is to activate the catoms belonging to the shape to be realized. One way of doing this is illustrated in the figure.

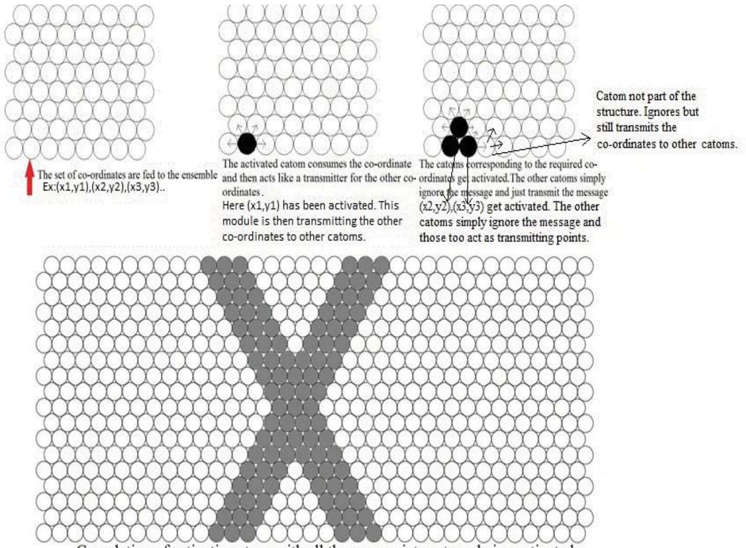
Initially the coordinates are to be fed into the ensemble. Loading several coordinates at a time might result in chaos. So we go for a technique used popularly in networking. We modify it here suitable for our application in claytronics. In claytronics we make the assumption that each module knows its position and location with respect to entire ensemble. Borrowing a technique used in a noiseless channel (stop-and – wait protocol [9]), the receiver sends/feeds one position co-ordinate to the ensemble and stops till it receives a confirmation from the ensemble and then sends the next co-ordinate. We have unilateral communication for the lattice positions but auxiliary ACK (simple tokens of acknowledgement) travel from the other direction. This is different from the arrangement of sending all the co-ordinates to the ensemble at once, in that we add flow control. The step followed is given thus.

-The loading of position co-ordinates is done with the co-ordinates corresponding to least co-ordinates first and then moving on to higher position values in the ascending order.

-Since every module knows its position, when it gets the message with the same co-ordinate it "consumes" that co-ordinate.

-If the co-ordinate it gets is not the same as its position co-ordinate, then it simply acts as a transmission point and passes on the co-ordinate to its neighboring module.

-If same then after consuming the co-ordinate, the module gets activated and for the other co-ordinates it encounters it acts as a transmission point.



Completion of activation stage with all the appropriate catoms being activated

-The process continues till all the modules that form the part of the shape has been activated. Alternatively till all the co-ordinates have been loaded.

-As seen in fig2 during activation the position co-ordinates are transmitted through the modules like a "chain reaction". This process can never end. A possible solution is that each catom has a memory in that if a catom gets d same co-ordinate the second time it kills it.

At the end of the process the modules which belong to the shape will be activated. The next step in the process is shape formation. A plausible approach has been given below.

Formation

At this point in the process the modules will be activated, the activated modules will have to be bonded. The bonding has to happen between activated modules. Figure illustrates one possible way to do this.

Initially the device initiates the process of bonding by sending a simple initiation message. This occurs the instant when it receives the last ACK frame. The steps involved are given thus.

-The catom which first gets the message will transmit it to its nearest neighbors.

-If the neighbors are activated modules themselves, then it will bond to the catom from which it got a message through the contact patches/points [3]

-If the neighbors are dormant modules the message is simply ignored.

-The bonded module then transmits the message to its nearest neighbors. The whole process continues till all the modules are bonded thus the shape is acquired.

There is the possibility that an already bonded module can get the message again. In such a case the catom simply ignores the message. One more possibility is that a catom might get "bonding message" from two catoms at the same time. Under such a condition the catom can bond to all the catoms or acknowledges the message one by one and bonds to the catom with the smaller X/Y or uses simple math calculations(such as

sqrt(x^2 + y^2) and bonds with the least resulting value. This process is illustrated in fig (3).

After the catoms have bonded, the remaining catoms which are not activated are just extracted from the ensemble to obtain the realization of the object by just the catoms. This is shown in the fig (4)

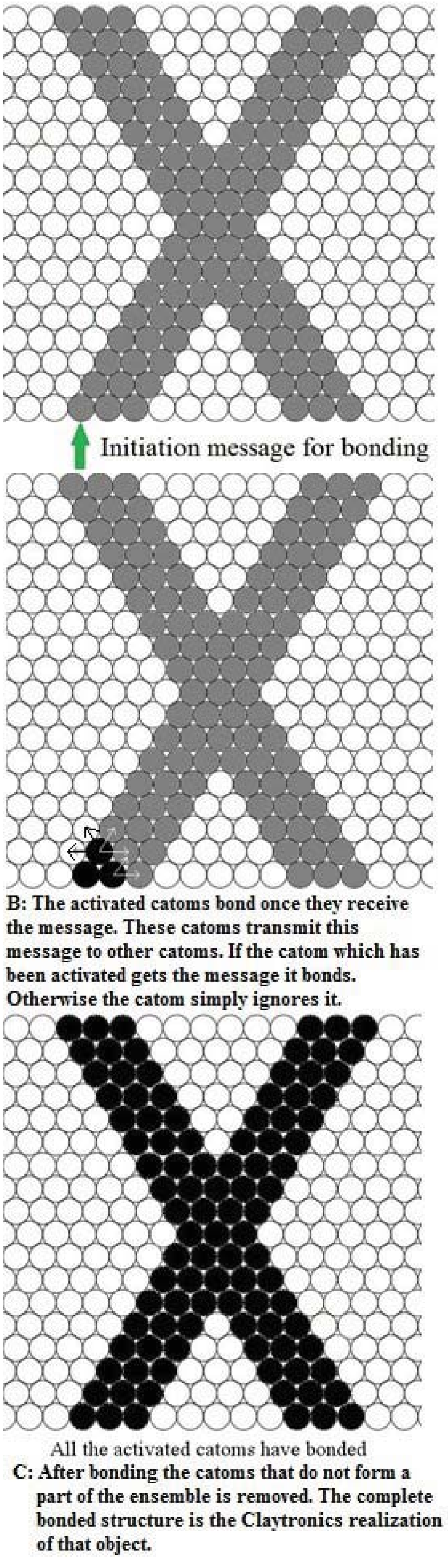


Fig (3)

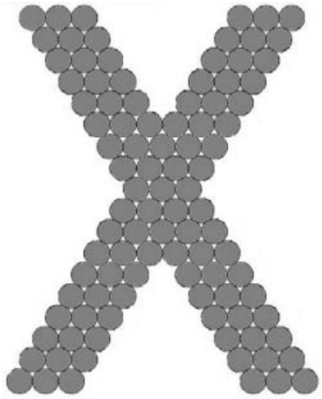


Fig (4)

IV. For 3-D Realization

The whole concept of claytronics can be extended to apply to 3-D objects as well. Here the catom ensemble is assumed to be 3 dimensional. It is also assumed that the computer knows all the coordinates of all the catoms. For image acquisition of a 3-D image, photographs of the object under consideration are taken from different angles. These photographs are then combined using sophisticated techniques to obtain a 3-D photograph of the object [10], [11]. More description of 2D to 3D conversion technique is beyond the scope of this paper. This 3-D image is compared with the ensemble and the coordinates of the catoms which are required are calculated and transmitted.

For shape reconstruction too, the ensemble is assumed to be 3 dimensional. Here the co-ordinates which are transmitted are input to the ensemble. The catoms belonging to the shape to be realized are activated in the same way as the 2-dimensional process. Applying the same principle of stop and wait protocol, the critical coordinates are fed to the ensemble one at a time, each time waiting for an ACK reply to confirm valid transmission. The catoms which aren't activated merely act like transmission paths and route the coordinates to its adjacent catoms. The activated catoms too act like transmission points for the other coordinates. After all the required catoms are energized, the activation stage is complete and the formation stage begins.

In the formation stage the actuation signal is input to a particular catom. This catom broadcasts the bond message to see which of its neighbors are activated. These activated catoms then bond. These bonded catoms individually broadcast the bond message to see which of its neighbors are activated and the process continues.

V. SCOPE FOR FURTHER DEVELOPMENT

There are several areas where improvement and research has to be done. In the two image acquisition techniques described, it might not be possible to acquire complete picture of the object and scale it down to the single catom scale. One possible solution may lie in advanced image acquisition techniques where each and every contour can be captured. The time delay involved in activation of certain catoms which are spread far and wide might has to be considered as it might not be insignificant. Efficient algorithms have to be implemented in such cases where the input signal is fed to many catoms instead of a single catom while at the same time achieving the desired result. The paper proposes a technique where the motion or orientation of catoms is not involved. This leads to significant advantages when it comes to power conservation but it might not be feasible in certain situations. For example 3-D realization of an abyss or any object with deep elevation changes, it would involve movement or removal of catoms from certain regions. Another constraint is it might not be possible to implement certain physical structures (for instance where much of the weight is concentrated on the upper half of the structure) with only the activated catoms. Some more additional catoms would also need to be activated to sustain the structure. This algorithm will work effectively for big 3-D realizations but for small 2-D realizations, hole motion algorithms can be used [4], [5]. When these considerations are incorporated into the algorithm, most of the limitations can be overcome and the algorithm would be effective in almost all situations.

VI. REFERENCES

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